LINEAR AND RADIAL DISPLACEMENT SENSOR

Cross Reference to Related Applications

This is a continuation-in-part of U.S. patent application serial no. 09/725,605, entitled "SENSOR FOR LINEAR AND RADIAL DISPLACEMENTS" filed November 29, 2000.

BACKGROUND OF THE INVENTION

1. Field of the invention.

The present invention relates to electromagnetic sensor assemblies, and, more particularly, to electromagnetic position sensor assemblies.

2. Description of the related art.

Electronic devices are an increasing part of everyday life and they are presently integrated in a large number of products, including products traditionally thought of as mechanical in nature, such as automobiles. To bridge the gap between mechanical movement and electronic control it is necessary to successfully integrate electronic and mechanical components. The gap is normally bridged by using devices such as sensors and actuators.

Position sensors are used to electronically monitor the position or movement of a mechanical component. The position sensor produces data that may be expressed as an electrical signal that varies as the position of the mechanical component changes. Position sensors are an important part of innumerable products, providing the opportunity for intelligent control of a mechanical device.

Various contact type sensors are known. For example, potentiometers are used which detect a change in an electrical signal due to the physical change in position of a wiping contact on a resistive element. Rotational position movement can be detected by coupling a shaft of a potentiometer to the shaft of a rotating mechanical component. Linear movement can be

detected using either a liner potentiometer or a rotating potentiometer that is coupled to a linear moving component using pulleys and a string or a belt to translate a linear motion to rotational motion. A problem with this type of sensor is the physical wearing of the rotating part, the wiping contact and the resistive element cause a drift in the electrical signal and lead to ultimate failure of the device.

Magnetic position sensors are generally a non-contact type of sensor and consist of a magnetic field sensing device which is usually stationary and a magnet that is attached to a moving component. As the magnet approaches the sensing device the magnetic field of the magnet is detected and the sensing device generates an electrical signal that is then used for counting, display, recording and/or control purposes. A problem with such sensors is that they depend on movement of the magnet and they are not able to provide information as to the static position of a mechanical component.

Other magnetic position sensors provide an indication of the displacement of the mechanical component by using a magnetic field sensing device which reports the intensity of a magnetic field from a magnet which is positioned on the mechanical component. The magnet is positioned and the magnetic field sensing device is located relative to the magnet in such a fashion as to cause the magnetic field to vary in the magnetic field sensing device as the magnet moves. A magnetic field sensing device may detect a static magnetic field from the magnet and report the field strength as a representation of the position of the mechanical component.

A magnetic positional sensor developed by the inventor, patented as U.S. Patent No. 5,818,223, entitled “ROTARY POSITION SENSOR WITH CIRCULAR MAGNET”, discloses a Hall effect device disposed within a cylindrically shaped magnet. The magnet having a magnetic field that varies from a north pole to a south pole as detected along a circular face of the magnet. The cylindrical magnet is mounted to a rotatable mechanical component and a Hall

effect device is positioned inside the cylindrical magnet with an air gap therearound. The Hall effect device has flux concentrators mounted thereto. The magnetic field produced by the cylindrical magnet is detected by the Hall effect device which in response thereto produces an electrical response representative of the magnet and hence the mechanical component's angular position.

A problem with such sensors is that they require large magnets.

Another problem with rotating sensors is that they require a stationary and a movable portion within a single assembly.

What is needed in the art is a compact modular position sensor which will provide static and moving position information using smaller magnets.

SUMMARY OF THE INVENTION

This invention relates to a position sensor which senses the linear or radial position of a mounted device. The sensor includes at least one elongated ferrous plate and a pair of magnets at spaced locations along the plate. An electronic signal generating device responsive to the flux density of the magnets along the plate is provided between the magnets with the plate being movable relative to the signal generating device.

Accordingly, it is an object of this invention to provide a position sensor which is of economic construction and which may sense the position of a mounted device either in a lateral orientation or a radial orientation.

It is another object of this invention to provide a position sensor which is for sensing the position of a mounted device and which allows a substantial relative movement between the mounted device and the sensor components.

A further objective of this invention is to provide a position sensor which utilized a Hall effect integrated circuit with the ability to sense either linear or radial movement.

Other objects of this invention will become apparent upon reading the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become more apparent and the invention will be better understood by reference to the following description of embodiments of the invention taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a side view of one embodiment of this invention;

Fig. 2 is a sectionalized end view of the embodiment of Fig. 1;

Fig. 3 is illustrative of three views of the embodiment of Fig. 1 showing the Hall effect device in three different operative positions;

Fig. 4 is a graph showing in the horizontal axis the position of the Hall effect device relative to the ferrous plates and in the vertical axis the magnetic field strength that is sensed by the hall effect integrated in circuit relative to the positions shown in Fig. 3;

Fig. 5 is a graph showing in the horizontal axis the linear position of the Hall effect integrated circuit and in the vertical axis the output signal strength of the Hall effect device relative to the position as shown in Fig. 3;

Fig. 6 is a side view in sectionalized form of another embodiment of this invention;

Fig. 7 is a sectionalized end view of the embodiment of Fig. 6;

Fig. 8 is a side view of a third embodiment of this invention;

Fig. 9 is a sectionalized end view of the embodiment of Fig. 8;

Fig. 10 is a graph showing in the horizontal axis the position of the Hall effect device in Fig. 8 relative to the ferrous plates of that figure and in the vertical axis the output signal strength of the Hall device relative to three positions of the Hall device;

Fig. 11 is a top view of another embodiment of this invention showing parallel curved plates;

Fig. 12 is a side view in form of the embodiment of Fig. 11;

Fig. 13 is a partial top view of still another embodiment of this invention showing curved plates;

Fig. 14 is a side view in sectionalized form of the embodiment of Fig. 13;

Fig. 15 is a partial top view of another embodiment of this invention showing curved plates and indicating the direction of rotation of the plates relative to the Hall effect device;

Fig. 16 is a side view in sectionalized form of the embodiment of Fig. 15;

Fig. 17 is a partial top view of another embodiment similar to the embodiment of Fig. 15 but showing two Hall effect devices;

Fig. 18 is a side view in sectionalized form of the embodiment of Fig. 17;

Fig. 19 is a partial top view of another embodiment of this invention showing opposed circular plates in which the direction of rotation of the plates and magnets relative to the Hall effect device is shown;

Fig. 20 is a side view in sectionalized form of the embodiment of Fig. 19;

Fig. 21 is a partial top view of another embodiment similar to he embodiment of Fig. 19 but having two Hall effect devices in use;

Fig. 22 is a side view in sectionalized form of the embodiment of Fig. 21;

Fig. 23 is a top view of still another embodiment of this invention showing concentrically spaced plates with the direction of the rotation of the plates and connected magnets relative to the Hall effect device being illustrated;

Fig. 24 is a side view in sectionalized form of the embodiment of Fig. 23;

Fig. 25 is a top view of another embodiment like the embodiment of Fig. 23 but utilizing two Hall effect devices;

Fig. 26 is a side view in sectionalized form of the embodiment of Fig. 25;

Fig. 27 is a side view of still another embodiment of this invention illustrating the use of three parallel plates interconnecting by magnets;

Fig. 28 is an end view in sectionalized form of the embodiment of Fig. 27;

Fig. 29 is a side view in sectionalized form of a further embodiment of this invention in which the plate is of tubular form;

Fig. 30 is a partial top view of the embodiment of Fig. 29;

Fig. 31 is a schematic representation of the top view of yet another embodiment of a positional sensor of the present invention;

Fig. 32 is a front view of the positional sensor of Fig. 31;

Fig. 33 is a schematic representation of the top view of yet another embodiment of a positional sensor of the present invention;

Fig. 34 is a front view of the positional sensor of Fig. 33;

Fig. 35 is a graph showing in the horizontal axis the position of a magnetic flux responsive device and in the vertical axis a voltage output of the magnetic flux responsive device for a configuration of the present invention illustrated in Figs. 2-3 and a configuration of the present invention illustrated in Figs. 31-34;

Fig. 36 is a schematic representation of the top view of a portion of yet another embodiment of a positional sensor of the present invention;

Fig. 37 is a front view of the positional sensor of Fig. 36;

Fig. 38 is a schematic representation of the top view of a portion of yet another embodiment of a positional sensor of the present invention;

Fig. 39 is a front view of the positional sensor of Fig. 38;

Fig. 40 is a schematic representation of the top view of a portion of yet another embodiment of a positional sensor of the present invention; and

Fig. 41 is a front view of the positional sensor of Fig. 40.

Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate one preferred embodiment of the invention, in one form, and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION OF THE INVENTION

This invention makes use of the principles generally stated in the United States Patents 5,818,223; 5,757,181; 5,332,965; and 4,970,463. These patents are incorporated herein by reference.

Referring to Figs. 1 and 2, position sensor 10 includes two low carbon ferrous plates 12 of preferably cold rolled steel. A magnet 14 is located at each end of the ferrous plates 12 which are in parallel arrangement. Each magnet 14 includes a north and south pole and ay be of the samarium cobalt type having an energy property of 22MGOe. Variations in the types of magnets and magnetic fields strengths along with different types of ferrous materials are within the scope of this invention. Located between plates 12 and also between magnets 14 is a magnetic flux

responsive device 16 in the form of a Hall effect integrated circuit such as a Micronas Hal 805. Again, the type of magnet responsive device can vary with application.

In normal operation the integrated circuit 16 would be stationary while the connected ferrous plates 12 and magnets 14 would move relative to the integrated circuits such as when being used for displacement movement measures of foot pedals, throttle positions, EGR valves and headlight levering systems in automobiles. It is, though, possible in some applications that the magnetic assembly including the plates would remain stationary while the magnetic responsive or integrated circuit moves relative to the fixed plates. The integrated circuit 16 is connected to a suitable readout circuit. The use of dual plates 12 provide for more assembly variations, allowing less critical locations between plates for the integrated circuit.

In Fig. 3, movement of the magnets 14 and connected plates 12 relative to integrated circuit 16 is illustrated for 3 positions. With the north/south poles of magnets 14 being oriented as illustrated so as to be aligned perpendicularly to plates 12, position 1 of fig. 3 shows the integrated circuit 16 located adjacent the left most magnet 14 as viewed in the figures with the magnetic field direction being illustrated as shown by arrow 18. As the relative movement between plates 12 and integrated circuit 16 takes place, integrated circuit 16 approaches a middle location as illustrated in position 2 of Fig. 3 in which a zero magnetic field is sensed by the integrated circuit. This is illustrated by arrow 20 in position 2. When further relative movement between the integrated circuit and plates occur with the integrated circuit now being located next to magnet 14 located at the right of the illustration as viewed in Fig. 3, the magnetic field directin is shown by arrow 22. Thus, in position 1 the magnetic field illustrated by arrow 18 would be at a maximum positive field illustrated by arrow 22.

In Fig. 4, there is a graph illustrative of the magnetic field strength relative to the linear position or location of the integrated circuit relative to plates 12 corresponding to the position illustrative of a mid-position in which the magnetic field is zero or neutral.

In Fig. 5, the magnetic field strength sensed by the integrated circuit 16 is converted by the Hall effect device into a voltage output signal. This output signal can then be converted by appropriate well-known circuitry into a position that relates to a linear location between magnets 14. Although only three positions of the Hall effect device relative to plates 12 are illustrated for purposes of producing the charts in Figs. 4 and 5, it is to be understood this relative movement is continued from side to side with the relative positions of the components being determined at any location of device 16 between magnets 14.

In Fig. 6, an alternative embodiment of the invention is shown in which only a single ferrous plate 12 is utilized in conjunction with magnets 14 and Hall effect integrated circuit 16. Ferrous plate 12 may have various configurations including being substantially flat as depicted in Fig. 6. The manner of operation of this position sensor 10′ is the same as described with respect to the embodiment of Figs. 1 and 2 with exception that only a single flux concentrator in the form of a single ferrous plate 12 is utilized. Magnets 14 may be located on either side of ferrous plate 12 or attached to the ends of ferrous plate 12.

The magnetic assemblies thus far described use the illustrated straight plates 12. It is understood that the parallel ferrous plates are not required to be straight, but can be curved and will perform in the same manner as described with regard to the figures of this invention. When plates 12′′ are curved or circular, the position sensor will be used to sense radial movement or positions as seen in Figs. 11-22. It is further contemplated that plate 12′′ may be cylindrical as seen in Figs. 29 and 30 or plates 12′′ may be circular and concentrically orientated with magnets 14 being located at diametrically opposite locations between the spaced circular plates as seen in

Figs. 23-26. Further two or more Hall effect devices could be located between the ferrous plates to produce multiple outputs. Also the magnetic assemblies can be stacked, that is three parallel plates 12 with a Hall effect device 16 between each adjacent pair of plates having a magnet 14 at each of their ends as seen in Figs. 27 and 28.

Although the invention as described herein utilized linear output magnetic responsive integrated circuits such as the Micronas Hal 805, it should be noted that alternative output schemes such as pulse width modulation in conjunction with a Micronas Hal 810 could also be utilized with the ferrous plates. In this scheme or embodiment, as relative movement takes place between the integrated circuit and the ferrous plates, the magnetic field strength and polarity would change with the output from the integrated circuit being a digital pulse with modulation cycling at a given frequency. The duty cycle of this digital output will have a relationship that varies in response to the magnetic field. For example, a 10 percent duty cycle from a Micronas Hal 810 would be equivalent to the linear output of 0.5 volts while a 90 percent duty cycle would be the equivalent to a linear output of 4.5 volts.

Figures 8 and 9 are illustrative of a third embodiment in which plates 12′ are of a variable width W. In this position sensor 10′′ a magnet 14 is located at each end of the plates 12′ and the Hal effect integrated circuit 16 is positioned between the plates. By varying the width of the ferrous plates, the slope of the output of the integrated circuit is changed as indicated by slope 26 in the graph of Fig. 10. This output of the integrated circuit is changed as indicated of being a constant linear line as produced by the embodiments of Figs. 1-6 with respect to the position of the integrated circuit relative to plates 12′, is sloped depending upon the configuration or the width of the plates.

The position sensors are constructed with the magnet assemblies, that is plates 12, 12′ and magnets 14, being shiftable or movable relative to the fixed Hall effect integrated circuit 16

through a suitable mechanical inter-connection which connects the magnetic assembly to a mounted device such as the previously mentioned foot pedal, throttle positioner, EGR valve, or headlights leveler.

Now, additionally referring to Figs. 31 through 34, there is shown a linear position sensor 50 including ferrous plates 52 and 54; magnets 56, 58, 60 and 62; and magnetic flux responsive device 16.

Ferrous plates 52 and 54 are spaced apart and arranged in a substantially parallel manner. Sufficient space exists between ferrous plates 52 and 54 to allow free movement of magnetic flux responsive device 16 therebetween. Magnet 56 is located with its north pole proximate one end of ferrous plate 52, and magnet 58 is located with its south pole proximate another end of ferrous plate 52. In a similar manner magnet 60 is located with its north pole proximate one end of ferrous plate 54, and magnet 62 is located with its south pole proximate another end of ferrous plate 54. Ferrous plates 52 and 54 are then arranged such that magnets 56 and 62 are located at the same end of linear position sensor 50, and in a like manner magnets 58 and 60 are located at an other end of linear position sensor 50.

Magnetic flux responsive device 16 may move beyond either end of ferrous plates 52 and 54, yet positional information from magnetic flux responsive device 16 is available as it traverses the length of ferrous plates 52 and 54. Such an arrangement alternatively allows multiple ferrous plate/magnet assemblies to exist in a spaced series arrangement thereby allowing locally accurate positional information to be obtained. While magnetic flux responsive device 16 is positioned between ferrous plates 52 and 54 the magnetic flux detected therebetween is substantially proportional to the relative linear position of ferrous plates 52 and 54, and magnetic flux responsive device 16. Magnetic flux responsive device 16 produces an electrical signal which

relates to the detected magnetic flux, the electrical signal being available to other circuitry for the positional control of a device, not illustrated.

Wa4 a6 Optionally, as shown in Fig. 34, shunts 66 may be positioned to intensify the magnetic field in ferrous plates 52 and 54. Shunts 66 can be configured such that magnetic flux responsive device 16 would still be able to travel beyond the end of ferrous plates 52 and 54.

An advantage of the embodiment illustrated in Figs. 31 through 34 is that a more linear output response is generated than the configuration illustrated in Figs. 1-3. Both the 'two magnet design' of Figs 1-3 and the 'four magnet design' of illustrated in Figs. 31-34 were tested relative to an ideal transfer function. The results of the test are illustrated in Fig. 35, which shows a nearly ideal response by the 'four magnet design', while the two magnet design deviates from the ideal transfer function.

Now, additionally referring to Figs. 36 and 37, there is shown another embodiment of the present invention, in the form of a radial position sensor 100 including ferrous plates in the form of ferrous rings 102 and 104; magnets 106, 108, 110 and 112; and magnetic flux responsive device 16.

Ferrous rings 102 and 104 are made of a ferrous material with an air gap 105 in each ring. Ferrous rings 102 and 104 are spaced apart and arranged in a substantially parallel manner. Air gap 105 of both ring 102 and 104 are disposed at substantially the same angular position. Sufficient space exists between ferrous rings 102 and 104 to allow free movement of magnetic flux responsive device 16 therebetween. Magnet 106 is located with its north pole proximate one end of ferrous ring 102 and magnet 108 is located with its south pole proximate another end of ferrous ring 102. In a similar manner magnet 110 is located with its north pole proximate one end of ferrous ring 104 and magnet 112 is located with its south pole proximate another end of ferrous ring 104. Ferrous rings 102 and 104 are then arranged such that magnets 106 and 112 are

located opposite each other, and in a like manner magnets 108 and 110 are located opposite each other.

Magnetic flux responsive device 16 is positioned between ferrous rings 102 and 104. Ferrous rings 102 and 104 rotate about an axis causing the magnetic field to vary in the vicinity of magnetic flux responsive device 16. Magnetic flux responsive device 16 detects the variation of the magnetic field and outputs an electrical signal, which is dependant upon the magnetic field strength. The electrical signal is then interpreted as a radial position of ferrous rings 102 and 104.

Optionally, as shown in Fig. 37, at least one shunt 116 may be used to intensify the magnetic field in ferrous rings 102 and 104. Shunts 116 are made of a ferrous material or a material which has a magnetic permeability which varies relative to temperature such as a copper-nickel alloy.

Now, additionally referring to Figs. 38 through 41, there is shown another embodiment of the present invention, in the form of a radial position sensor 120 including ferrous plates in the form of ferrous rings 102 and 104; magnets 122 and 124; and magnetic flux responsive device 16.

Ferrous rings 102 and 104 are made of a ferrous material with an air gap 105 in each ring. Ferrous rings 102 and 104 are spaced apart and arranged in a substantially parallel manner. Air gap 105 is either traversed on the outside of rings 102 and 104 by magnets 122 and 124 as shown in Fig. 39, or magnets 122 and 124 substantially fill air gap 105 as shown in Fig. 41.

Optionally, as shown in Figs. 39 and 41, at least one shunt 117 may be positioned to mitigate the magnetic field in ferrous rings 102 and 104. Shunts 117 can be made of a ferrous material or a material which has a magnetic permeability which varies relative to temperature such as a copper-nickel alloy. The use of a temperature sensitive magnetic permeability shunt

compensates for variations in temperature, keeping the magnetic field strength between rings 102 and 104 more uniform through temperature variations.

The embodiments of the present invention, illustrated in figures 36 through 41, allow a continuous rotation of ferrous rings 102 and 104 relative to magnetic flux responsive device 16. When magnetic flux responsive device 16 is proximate air gap 105, the magnetic field is at its strongest and the change in the magnetic field is not as uniform as in other areas of the space between rings 102 and 104. As air gap 105 is moved past magnetic flux responsive device 16 the direction of the magnetic flux rapidly switches. This can advantageously be used to provide an electrical output, from magnetic flux responsive device 16, which indicates an indexed output.

Alternatively, ferrous rings 102 and 104 may be segmented, having multiple air gaps, with magnets disposed at each air gap as described in the foregoing embodiments. Further, the air gaps of each segment of ferrous ring 102 may be angularly positioned relative to the air gaps in ferrous ring 104 to produce a particular electrical waveform from magnetic flux responsive device 16 as rings 102 and 104 rotate relative to magnetic flux responsive device 16.

~~Ferrous plates 12 and rings 102 and 104 can be formed in varying widths, as shown in Fig. 8, be of varying thickness and shaped to vary the distance between plates 12,1 and between rings 102 and 104. Each variation in thickness, width and shape is used to purposely alter the electrical output of magnetic flux responsive device 16.~~

Alternatively, two or more magnetic flux responsive devices 16 can be positioned at particular radial positions relative to ferrous rings 102 and 104. The electrical output from magnetic flux responsive devices 16 is conditioned by circuitry, which use output signals from magnetic flux responsive devices 16, during the portion of rotation in which a particular magnetic flux responsive device 16 is located away from air gap 105.

In yet another alternative form, ferrous rings 102 and 104 may be cylindrical of differing diameters with one cylindrical ring fitting inside the other with a space therebetween sufficient for the locating of magnetic flux responsive device 16. Cylindrical ferrous rings 102 and 104 each have an air gap along the length thereof. Magnets, configured as in the forgoing embodiments, provide a magnetic field to cylindrical ferrous rings 102 and 104.

In yet another alternative configuration, more than one radial position sensor 100 or 120 are located coaxially, thereby providing multiple output signals to external circuitry, which process the multiple outputs to determine the radial position, velocity or acceleration of a target object such as a shaft.